United States Military Academy
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Advanced Field Artillery System Trade-off Analysis: TOT vs. ROF

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OPERATIONS RESEARCH CENTER
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THIS REPORT FOCUSES ON THE RESULTS OF RESEARCH EFFORTS ON METHODOLOGIES AND THE ADVANCED FIELD ARTILLERY SYSTEM (AFAS). OUR GOAL WAS TO CONCEPTUALIZE AND DESIGN ALTERNATIVE AFAS CAPABILITIES IN THE JANUS COMBAT SIMULATION TO EVALUATE THEIR EFFECTIVENESS ON TOMORROW'S BATTLEFIELD UNDER SEVERAL DIFFERENT SCENARIOS AND MISSIONS. ADDITIONALLY, THE TEAM USED THE RESULTS TO VERIFY A METHODOLOGY FOR PREDICTING COMBAT SIMULATION RESULTS FOR ALTERNATIVE SENSITIVITY ANALYSES. THE RESULTS OF THIS FIRST PHASE INDICATE AS NEED FOR A FASTER DELIVERY SYSTEM TO MASS FIRES AT THE RIGHT TIME IN THE RIGHT PLACE ON THE FUTURE BATTLEFIELD.

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A TECHNICAL REPORT
OF THE
OPERATIONS RESEARCH CENTER
UNITED STATES MILITARY ACADEMY

Directed by
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25 June 1993

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Vitae

MAJ George F. Stone III

Born in November 1955, MAJ Stone graduated in 1980 from the US Military Academy, and has served in field artillery units in both CONUS and Europe. While assigned to the 3 Infantry Division, MAJ Stone commanded a nuclear-capable, 6-gun, 155mm battery for 18 months and a headquarters battery for 13 months. In 1989 he was awarded a Masters of Science Degree in Industrial Engineering (OR) from Texas A&M University. He published and presented his research project, Military Simulations for Noncombat Operations in Military Review and military operations research conferences. As an Assistant Professor of Systems Engineering, MAJ Stone organized and integrated the U.S. Military Academy's Combat Simulation Laboratory as part of the instruction and development of three separate courses in combat modeling and combat system design. MAJ Stone directed cadet and faculty research in the following areas: The Enhanced Integrated Soldier System, Smart Mortars, The Janus Enhanced Data Analyzer, Advanced Field Artillery System Study, C2 MOE for the Eagle Combat Simulation and Synchronized Intelligent Mine Systems. He graduated from the resident Command and General Staff College in 1993 and is enroute to earn a doctoral degree at the University of Central Florida. His military awards include the Meritorious Service Medal (1 OLC), the Army Commendation Medal and the Army Achievement Medal (3 OLCs).

MAJ James Moughon

MAJ James Moughon graduated from the University of Georgia in 1979 and received his masters in Operations Research from the Naval Postgraduate School in 1989. MAJ Moughon has served in command and staff positions in various field artillery units. He also attended the resident Command and General Staff College in 1990 prior to his assignment to the USMA faculty as an assistant professor for Systems Engineering. MAJ Moughon is currently in the 18th Airborne Corps Fire Support Element at Fort Bragg, North Carolina.

SFC Paul West

SFC Paul West has earned Masters of Business Administration from Long Island University. He is an armor noncommissioned officer and an assistant professor who teaches and develops courses in the Department of Military Instruction field of study at the U.S. Military Academy. He was responsible for integrating the Janus (Army) combat simulation into the DMI curricula under the auspices of the Department of History. SFC West's relationship and tactical knowledge made him an invaluable asset to the completion of the AFAS project.

Acknowledgments

We thank MAJ Mike Clark and LTC William Sole, USAFAS DCD, for their interest and assistance in providing a branch-related topic for us to research in the USMA Combat Simulation Lab. The project created an opportunity for all of us to refresh artillery experiences and prepare ourselves for future assignments.

We also appreciated the support and guidance LTC James Armstrong gave concerning modeling of AFAS.

CPT Mark Tillman, CPT Sue Romans and 2LT Clemens Kruse also devoted their time to the study. MAJ James Watson was crucial for continuity and will hopefully carry on this important effort.

Table of Contents

Appendices

Executive Summary

This report focuses on the results of research efforts on methodologies and the Advanced Field Artillery System (AFAS). Our goal was to conceptualize and design alternative AFAS capabilities in the Janus combat simulation to evaluate their effectiveness on tomorrow's battlefield under several different scenarios and missions. Additionally, the team used the results to verify a methodology for predicting combat simulation results for alternative sensitivity analyses. The results of this first phase indicate a need for a faster delivery system to mass fires at the right time in the right place on the future battlefield.

The team developed several scenarios to fully exploit the effects of fire support in the defense. The scenarios involved a moving enemy force against static defensive friendly units. We evaluated several AFAS alternatives in terms of rate-of-fire and time-on-target capabilities on Janus (A). The AFAS either had an enhanced rate-of-fire or improved capability for providing more rounds in time-on-target missions. We conducted replications of each design matrix to test for significance of different factors or alternatives as part of the analysis. Once all runs were conducted, data were collected using the Janus Enhanced Data Analyzer. Next, the information was organized on a spreadsheet to conduct the factorial design analysis and response surface methodology. The measures of effectiveness and graphical analyses showed significant results. The results indicate: 1) Increasing the rate-of-fire significantly reduces the required amount of rounds for a kill, as well as, a greater number of kills for slow enemy forces; 2) Response surface methodology is a viable method for predicting parametric variations between factors such as ROF and TOT. SFC West also conducted a 1000-target analysis to determine whether cumulative effects exceeded individual target effects under time-on-target and rate-of-fire. The results indicated that more rounds per TOT and more rounds per minute for ROF increased the total number of kills, but with an expected decrease in efficiency in terms of kills per rounds.

As indicated in appendix A, the project was briefed from both an analytical methodology standpoint at the Military Operations Research Symposium and from an combat developer's view to AFAS key personnel at Fort Sill. The Department of Systems Engineering has incorporated response surface methodologies as a predictive method into research work on other projects. The project was well-received at both locations, but transitions to new assignments by almost all of the analysts and MAJ Clark precluded further research. Ft. Sill's AFAS project leaders are currently considering using USMA analysts in the latest AFAS Study Plan.

Appendix A
AFAS Study Results: Phase I

Wargaming Lab
Operations Research Center
United States Military Academy
West Point, New York 10996

Designing & Predicting Effects in Combat Simulations

Presented to

MORSS 60

Monterey, CA
June 23, 1992

Analysts: MAJ George Stone
MAJ James Moughon
SFC Paul West, DMI

Departments of
Military Instruction &
Systems Engineering
United States Military Academy
West Point, New York 10996

Advanced FA System Trade-Off Analysis: TOT vs. ROF

Presented to

DCD, USAFAS

July 20, 1992

Analysts: MAJ George Stone
MAJ James Moughon
SFC Paul West

AFAS TOT/ROF Trade-Off Analysis

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Purpose: Investigate the Delivery Capabilities of the Advanced Field Artillery System (AFAS) for enhanced combat effectiveness

Scenario: Southwest Asia (U.S. Mech Inf Defending vs. T-72/BMP force)

Factors to Investigate:

- Rate of Fire (ROF)
- Time-On-Target (TOT)
- Varying Percentages of Soft and Hard Targets

AFAS TOT/ROF Considerations

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Time-on-Target

How many volleys appear to be sufficient for combat effectiveness?

Rate of Fire

How fast a rate of fire is needed for the AFAS?

Modeling AFAS in Janus

- On-Board Technical & Tactical Fire Control
- Automatic Gun System
- Advanced POS/NAV
- Advanced Munitions & Propellants

AFAS: Study Methodology

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- Set up the SWA Scenario as Desired By FT Sill
- Conduct 10 Runs for each Design Point
- Review Battles for Consistency in Using Indirect Fires
- Graph Measures of Effectiveness for Trends
- Analyze MOE for Main/Interaction Effects
- Predict Middle-value Variations using Response Surface Methodology (RSM)
- Verify RSM by Running Scenario w/Middle Values

Fire Plan

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Time	Mission
1:00	- Fire Target AB001 to coincide with execution of cratering charge at 164610.
3:00	- Fire Group Bravo (AB002, AB003, AB004) to bottle the enemy north of the 60 gridline and destroy him as he begins to deploy north of the 61 gridline.
5:00	- Fire Target AC001, stationary trucks and troops in the open.
7:00	- (Scenario 1) Fire Targets AD003 and AD005 to destroy enemy armor and block withdrawal from direct fire engagement area.
	- (Scenario 2) Fire Target AD001, moving trucks in the open.
9:00	- (Scenario 1) Fire Targets AD003 and AD004.
	- (Scenario 2) Fire Target AD002, moving trucks in the open.

Classification of Enemy Soft and Hard Targets

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Hard Tgts	Soft Targets
T-80 MBT	Riflemen
T-72 MBT	RPG-7
T-62 MBT	Lt MG
BMP-2 IFV	AGS-17
BMP-1 IFV	ADA Tm
BMP CP Veh	120mm Mtr
BRDM-AT	152mm How
	122mm Mortar
	Truck Utility
	Truck POL
	Motorcycle

High-Resolution Force Structure SWA Mech Infantry Scenario #1

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BLUE SYSTEMS

28 M1A1 Tank
30 M2 Bradley Fighting Veh
12 M901 TOW Veh
72 Infantry Riflemen
18 Med AT Wpn
6 FIST Tm
6 FIST-V
1 OH-58D Helicopter

Indirect Fire
8 Adv FA System
6 M106 (4.2") Mortar

RED SYSTEMS

Moving
31 T-72 Tank
111 BMP-2
19 BMP-1
419 Riflemen
81 RPG-7
135 Lt MG
18 AGS-17
9 ADA Tm
24 120mm Mtr
24 BRDM-AT

UMCP (Stationary Tgts)
3 ea T-62, T-80, BMP-2
15 Riflemen
5 Truck Util
2 Truck POL
1 BMP Cmd Post
1 Motorcycle

Indirect Fire
72 152mm How
18 122mm Mortar

20% Soft Targets/ 80% Hard Targets

High-Resolution Force Structure
SWA Mech Infantry Scenario #2

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BLUE SYSTEMS

28 M1A1 Tank
30 M2 Bradley Fighting Veh
12 M901 TOW Veh
72 Infantry Riflemen
18 Med AT Wpn
6 FIST Tm
6 FIST-V
1 OH-58D Helicopter

Indirect Fire
8 Adv FA System
6 M106 (4.2") Mortar

RED SYSTEMS

Moving
31 T-72 Tank
111 BMP-2
19 BMP-1
419 Riflemen
81 RPG-7
135 Lt MG
18 AGS-17
9 ADA Tm
24 120mm Mtr
24 BRDM-AT

Indirect Fire
72 152mm How
18 122mm Mortar

UMCP (Stationary Tgts)
3 ea T-62, T-80, BMP-2
15 Riflemen
5 Truck Util
2 Truck POL
1 BMP Cmd Post
1 Motorcycle

Additional Targets
10 Trucks
30 Riflemen
3 BRDM-AT
2 SA-13
3 ZSU-23-4
1 122mm MRL
2 Motorcycles

60% Soft Targets/ 40% Hard Targets

AFAS Variation Levels

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Rate of Fire	Time on Target
1. 8 rds/minute	1. 4-rd volleys
2. 10 rds/minute	2. 6-rd volleys
3. 12 rds/minute	3. 8-rd volleys

- Levels 1 and 3 are the low and high levels for the Factorial Design

- *Level 2 (middle-level values) will be predicted by Response Surface Methodology and then compared with the output from the actual runs.*

AFAS: Full Factorial Design

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Conduct *10 Runs* of each point to Assess Factors

FACTOR	(-)	(+)
1. ROF or TOT	8rpm/ 4-rd Volleys	12rpm/ 8-rd Volleys
2. Target Type	20%Soft/ 80% Hard	60%Soft/ 40% Hard

* AFAS used DPICM in all missions

Design Point	Factor 1	Factor 2	Response**
DP1	-	-	R1
DP2	+	-	R2
DP3	-	+	R3
DP4	+	+	R4

Graph other Measures:
- Det/Fire/Kill Rgs over time
- #Red Systems Killed by Type

** Six MOE (Responses) used:
- AFAS Rds/Kill
- Det Ratio
- DF Kills of Red
- DF Engage Rg
- IF Kills of Red
- AFAS Percent Contrib

Total Kills by AFAS on Hard Targets

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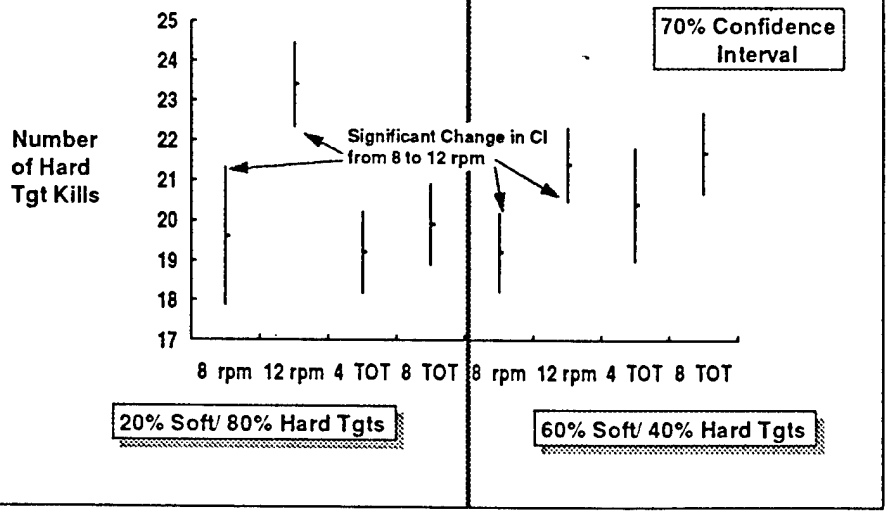

Total Kills by AFAS on Soft Targets

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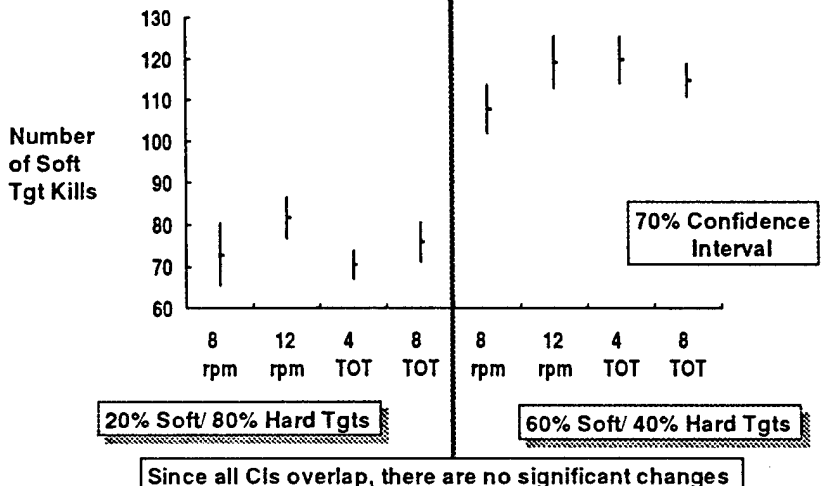

Since all CIs overlap, there are no significant changes

Rounds per Kill Time-on-Tgt vs. Rate of Fire

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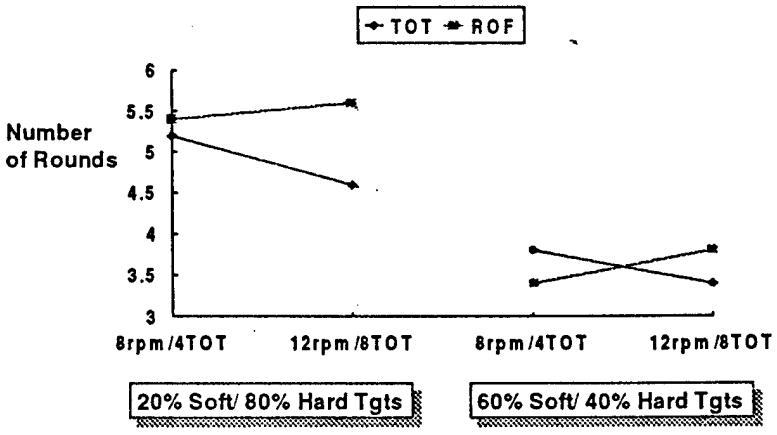

Main Factor Effects
Time-on-Tgt vs. Rate of Fire

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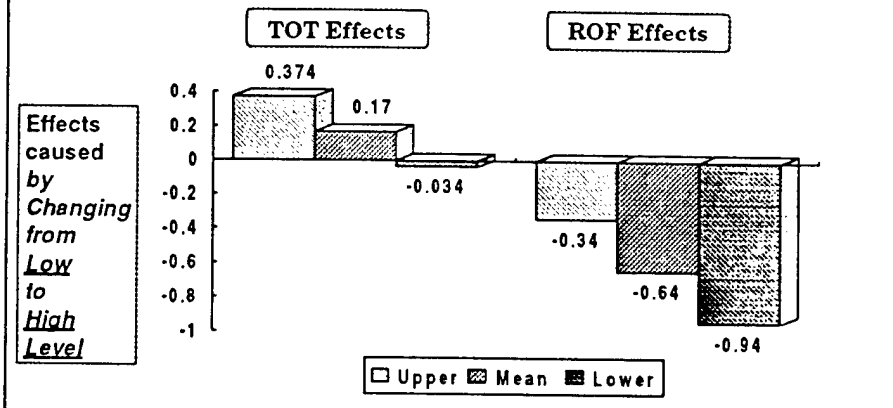
MOE #1: #Indirect Rounds Expended per Kill of Red Systems



Only *ROF* Missions are Significant within a 70% Confidence Interval

Main Factor Effects
20% vs. 60%Soft Targets

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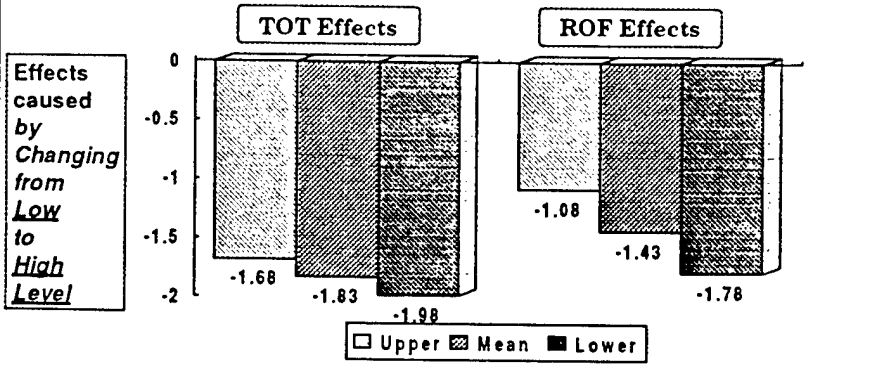
MOE #1: #Indirect Rounds Expended per Kill of Red Systems



Both *TOT & ROF* Missions are Significant within a 70% Confidence Interval

Direct Fire Kills
Time-on-Tgt vs. Rate of Fire

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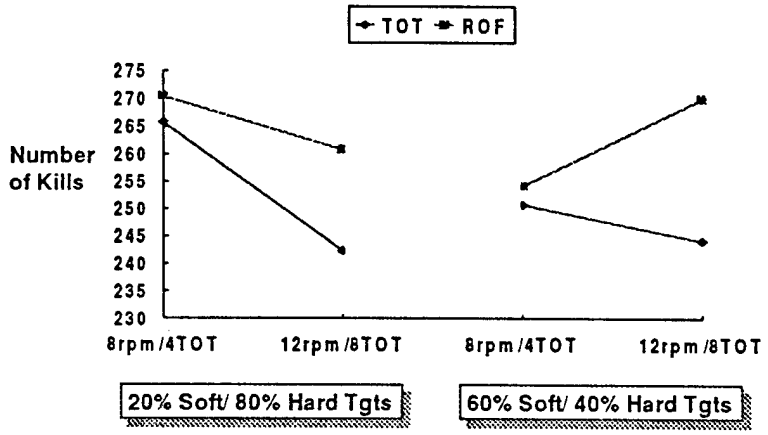

Main Factor Effects
Time-on-Tgt vs. Rate of Fire

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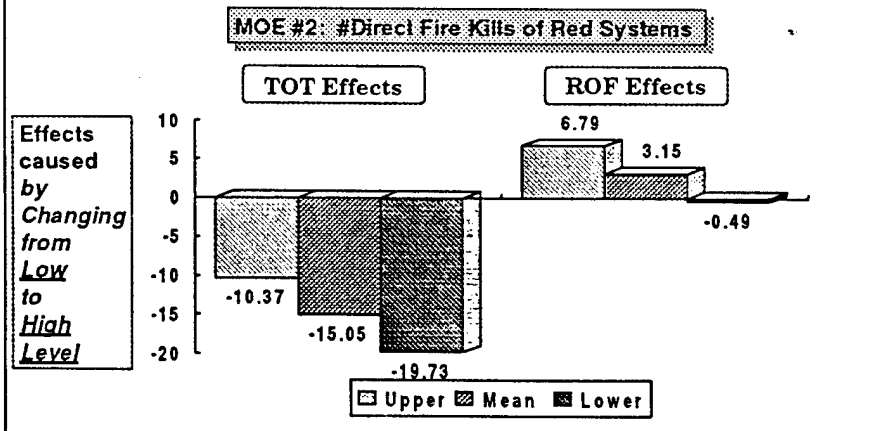

Only *TOT* Missions are Significant within a 70% Confidence Interval

Main Factor Effects
20% vs. 60% Soft Targets

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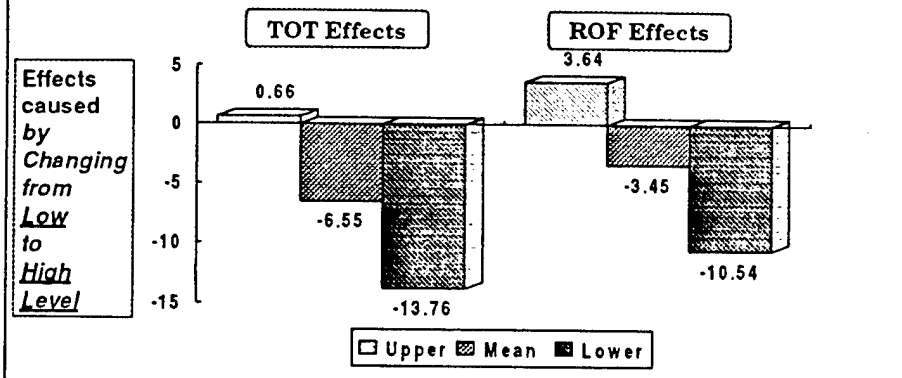
MOE #2: #Direct Fire Kills of Red Systems



Neither *TOT nor ROF* Missions are Significant within a 70% Confidence Interval

Indirect Fire Kills
Time-on-Tgt vs. Rate of Fire

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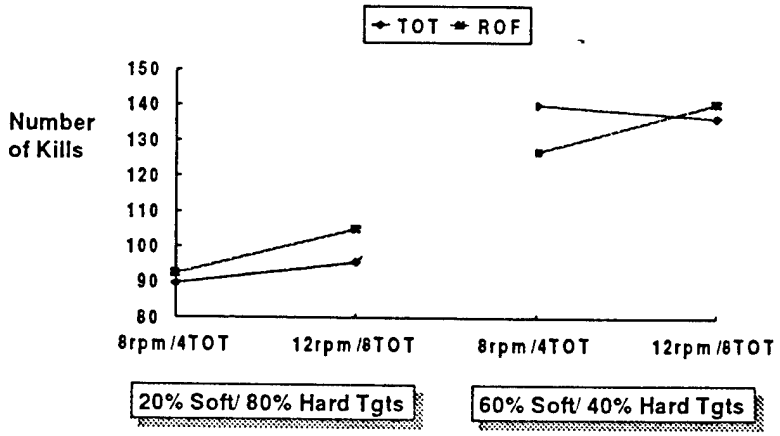

20% Soft/ 80% Hard Tgts

60% Soft/ 40% Hard Tgts

Main Factor Effects
Time-on-Tgt vs. Rate of Fire

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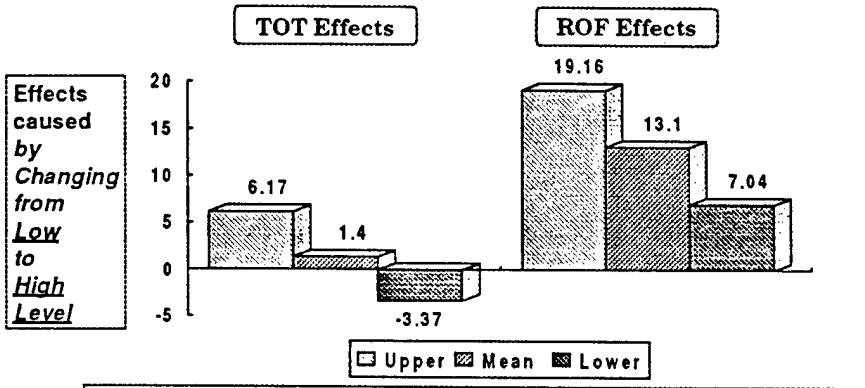
MOE #3: #Indirect Fire Kills of Red Systems



Only *ROF* Missions are Significant within a 70% Confidence Interval

Main Factor Effects
20% vs. 60% Soft Targets

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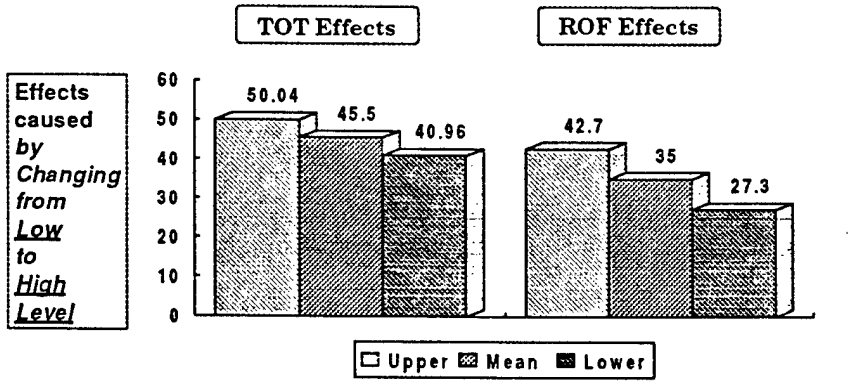
MOE #3: #Indirect Fire Kills of Red Systems



Both *TOT* & *ROF* Missions are Significant within a 70% Confidence Interval

Engagement Ranges (Direct Fire)
Time-on-Tgt vs. Rate of Fire

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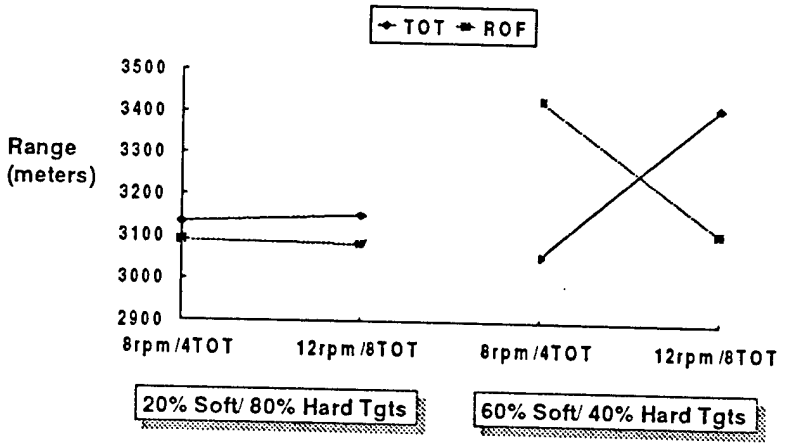

Main Factor Effects
Time-on-Tgt vs. Rate of Fire

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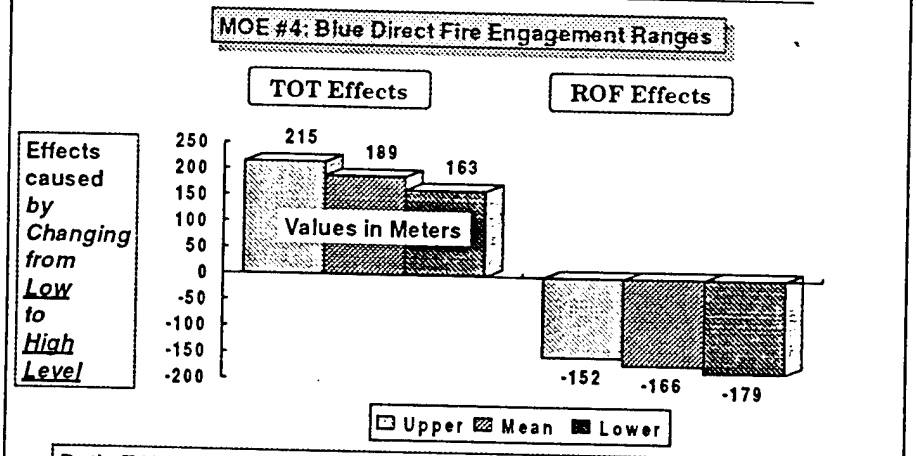

Main Factor Effects
20% vs. 60% Soft Targets

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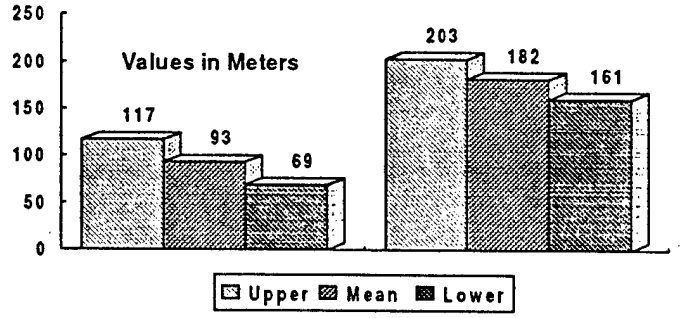
MOE #4: Blue Direct Fire Engagement Ranges

TOT Effects | ROF Effects

Effects caused *by Changing from* ***Low*** *to* ***High*** ***Level***



Both *TOT* & *ROF* Missions are Significant within a 70% Confidence Interval

Detection Ratio
Time-on-Tgt vs. Rate of Fire

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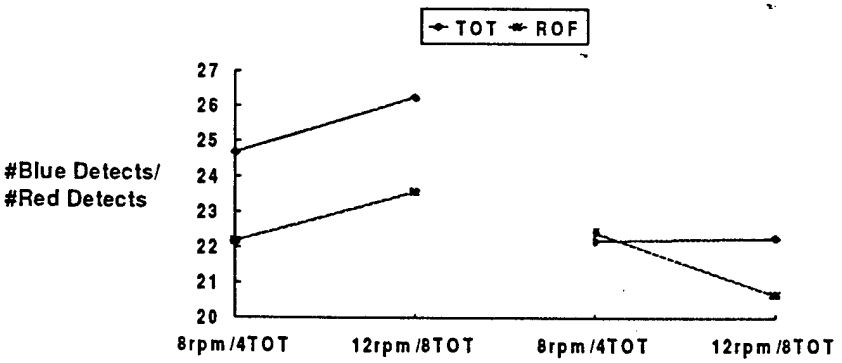

20% Soft/ 80% Hard Tgts

60% Soft/ 40% Hard Tgts

Main Factor Effects
Time-on-Tgt vs. Rate of Fire

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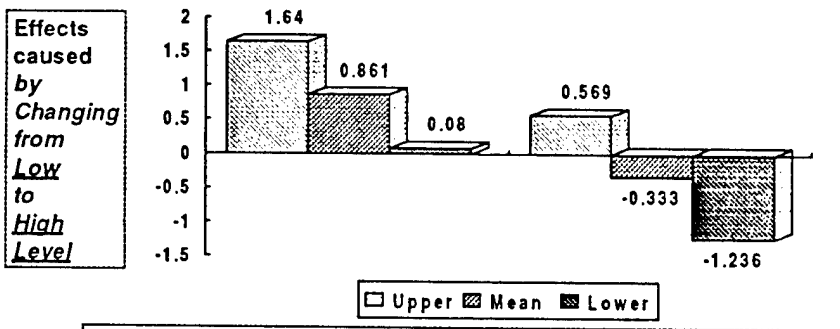
MOE #5: #Blue Detects of Red/ #Red Detects of Blue



Only *TOT* Missions are Significant within a 70% Confidence Interval

Main Factor Effects
20% vs. 60% Soft Targets

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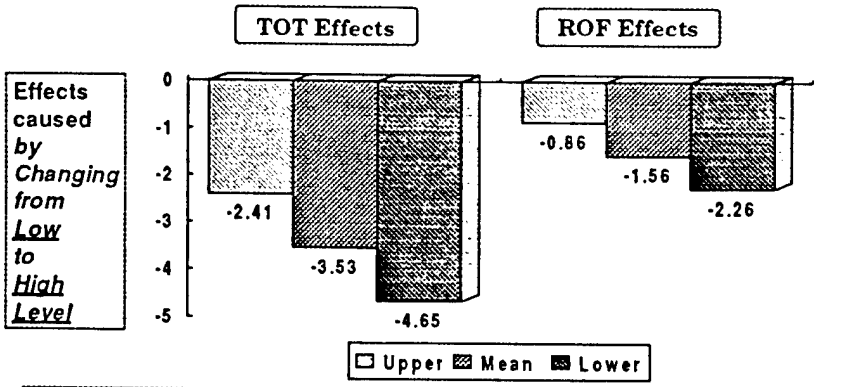
MOE #5: #Blue Detects of Red/ #Red Detects of Blue



Both *TOT & ROF* Missions are Significant within a 70% Confidence Interval

Total Kills
Time-on-Tgt vs. Rate of Fire

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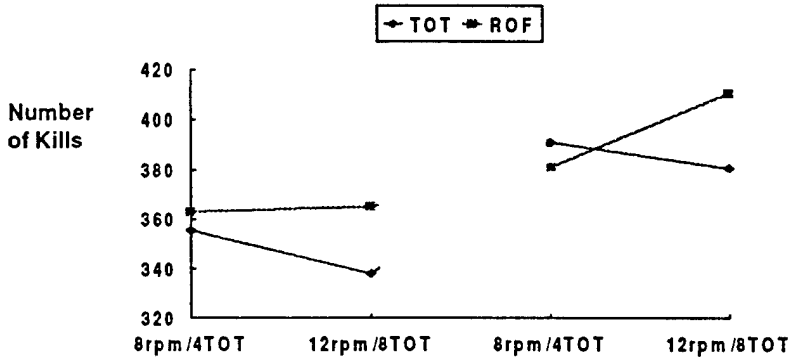

Percent Contribution of AFAS
Time-on-Tgt vs. Rate of Fire

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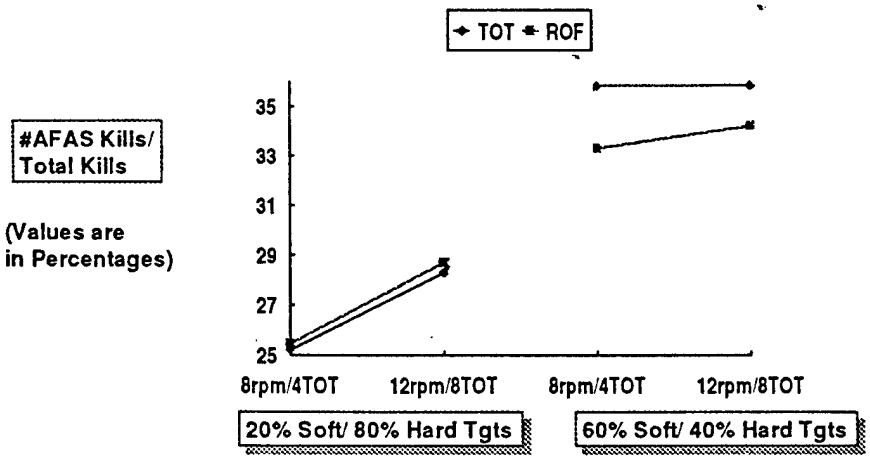

Main Factor Effects
Time-on-Tgt vs. Rate of Fire

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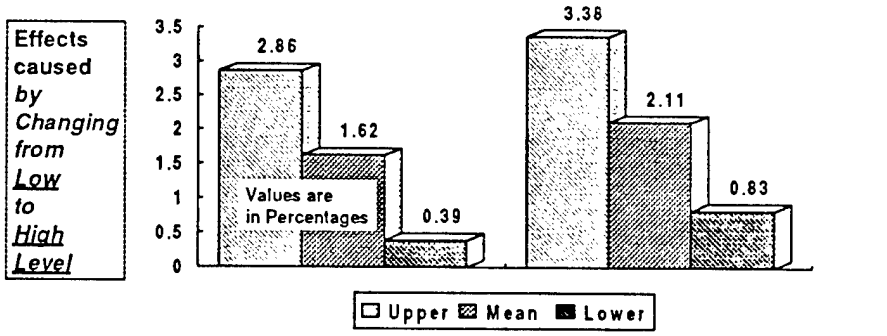
MOE #6: AFAS Percent Contribution of Red Kills
AFAS grouped with M1A1 MBTs, M2 BFVs & M901 TOWs



Both *TOT* & *ROF* Missions are Significant within a 70% Confidence Interval

Main Factor Effects
20% vs. 60% Soft Targets

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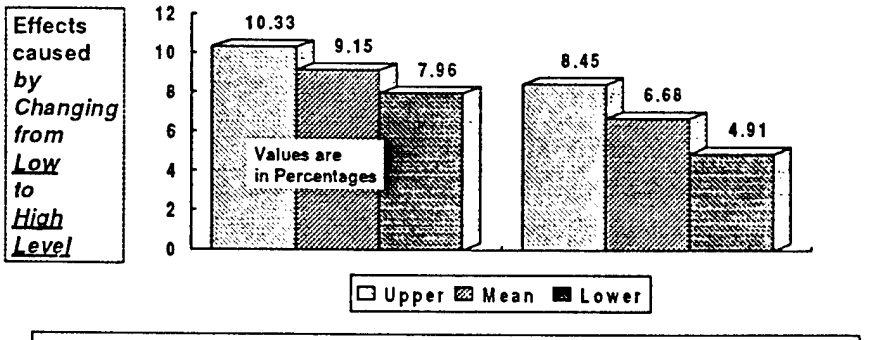
MOE #6: AFAS Percent Contribution of Red Kills
AFAS grouped with M1A1 MBTs, M2 BFVs & M901 TOWs



Both *TOT* & *ROF* Missions are Significant within a 70% Confidence Interval

Summary of DOE Results

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Significant Main Effects

MOE	Mission Factor
Arty Rounds/Kill	*ROF*
Direct Fire Kills	TOT
Indirect Fire Kills	ROF
DF Engagement Rg	TOT & ROF
Detection Ratio	TOT
Percent Contribution	*TOT & ROF*

Look at these MOE for RSM

Response Surface Method

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Premise: RSM can be used to Predict the Effects of a Simulation

Proved by: Comparing the RSM Values for Mid-Levels in ROF & TOT with the actual averages obtained from the runs in Janus

MOE to Compare:

1. #Indirect Fire Rounds per Red System Killed
2. AFAS Percent Contribution vice M1, M2 and M901 systems

RSM for AFAS Rds/Kill

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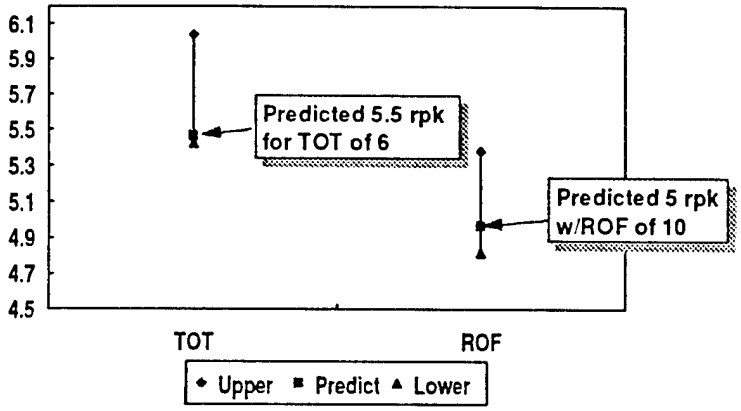
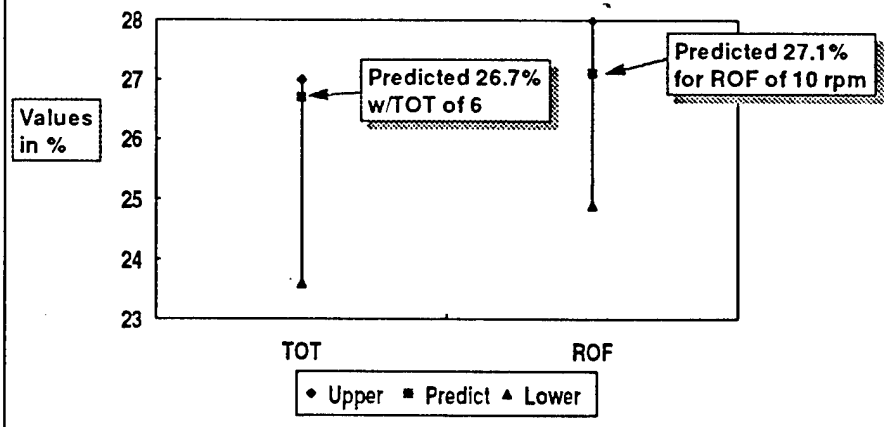
20% Soft Tgts/80% Hard Tgts
TOT of 6 Rds & ROF = 10 Rds/Min



RSM for AFAS % Contrib

ORCEN-Center of Excellence

20% Soft Tgts/80% Hard Tgts
TOT of 6 Rds & ROF = 10 Rds/Min



AFAS Study Conclusions

ORCEN Center of Excellence

Comparison of Factorial Design of Experiments Results

1. Increasing the rate of fire showed a significant decrease in artillery rounds per kill (-0.64 rpk).

2. For Indirect Fire Kills, there was a significant increase (13.1 kills) when changing from 8 rds/min ROF to 12 rds/ min.

3. AFAS percent contribution significantly increased in both methods of employment (1.62% for TOT and 2.11% on ROF).

AFAS Study Conclusions

ORCEN Center of Excellence

Response Surface Methodology Results

1. For both scenarios, predictions of artillery rounds per kill for a TOT of 6 rds and a ROF of 10 rds/min were within the actual runs' confidence intervals.

2. AFAS percent contribution predictions were also within the bounds of confidence intervals for the same cases as in '1'.

3. RSM does show potential for reducing the amount of runs required for a study of parameters, such as TOT or ROF.

AFAS Study Conclusions

ORCEN Center of Excellence

Comparison of Graphs & Confidence Intervals about Means

1. In Killing Hard Targets, the 12 rds/min ROF is most effective in a 20% Soft/80% Hard target distribution

2. For Soft Targets, there appears to be no significant difference among any of the methods, although a higher ROF or TOT shows a larger mean.

3. The Method of Employment shows no sigificant effect on Direct Fire Engagement Ranges even though the Factorial Design Analysis suggested minor changes in effects due to changing factors.

1000 Target Methodology

ORCEN Center of Excellence

1. Based on Soviet-style tank company in wedge formation.
2. 100 target groupings; 10 vehicles per group.
3. Two platoons with 3 vehicles; 1 with 4 (includes HQ tank).
4. One event per method of engagement:
   - -- One 8-round volley per group under 8 TOT
   - -- Twelve rounds, 5 seconds apart, per group under 12 ROF
5. ROF rounds are spread over a 1-minute attack.
6. Five runs for each method of engagement.
7. Trucks substituted for tanks at the same locations.

Appendix B
Factorial Design Analysis: TOT

MOE = #Direct Fire Kills for TOT Missions
Block Name: DFK_TOT

Design Point	TOT	Tgt Type	Factor Interaction	Run 1	Run 2	Run 3	Run 4	Run 5	Run 6	Run 7	Run 8	Run 9	Run 10	Average
1	-	-	+	271	274	274	249	282	240	261	264	253	290	265.8
2	+	-	-	259	256	248	254	239	235	201	239	245	247	242.3
3	-	+	-	255	222	243	263	284	259	211	256	262	253	250.8
4	+	+	+	229	242	241	277	289	246	191	260	227	240	244.2

Factor#1 Effects				-19	1	-14	9.5	-19	-9	-40	-10.5	-21.5	-28
MEAN	-15.05												
SDEV	13.34813												
Half-Lgth	4.677513												
Upper	-10.3725												
Lower	-19.7275												
Signif?	Yes												
Factor #2 Effects				-23	-33	-19	18.5	26	15	-30	6.5	-4.5	-22
MEAN	-6.55												
SDEV	20.59059												
Half-Lgth	7.215451		t.85 =	1.10814									
Upper	0.665451												
Lower	-13.7655												
Signif?	No												
Interaction Effects				-7	19	12	4.5	24	-4	20	14.5	-13.5	15
MEAN	8.45												
SDEV	12.12322												
Half-Lgth	4.248275												
Upper	12.69828												
Lower	4.201725												
Signif?	Yes												

MOE = Percent Contribution of AFAS for TOT Missions
Block Name: PER_TOT

Design Point	TOT	Tgt Type	Factor Interaction	Run 1	Run 2	Run 3	Run 4	Run 5	Run 6	Run 7	Run 8	Run 9	Run 10	Average
1	-	-	+	25.55%	23.68%	21.04%	31.97%	20.11%	27.27%	26.68%	25.21%	27.71%	22.87%	25.21%
2	+	-	-	28.25%	24.93%	27.27%	23.49%	30.52%	28.13%	40.18%	29.29%	26.43%	24.46%	28.31%
3	-	+	-	33.59%	43.08%	38.94%	33.92%	29.18%	36.05%	43.58%	32.28%	37.62%	29.92%	35.84%
4	+	+	+	35.49%	36.15%	33.42%	32.27%	27.93%	35.26%	44.48%	36.89%	40.73%	37.17%	35.86%

Factor#1 Effects			2.30%	-2.84%	0.35%	-5.07%	4.58%	0.04%	7.20%	4.35%	0.91%	4.42%	
MEAN	1.62%												
SDEV	3.53%												
Half-Lgth	1.24%												
Upper	2.86%												
Lower	0.39%												
Signif?	Yes												
Factor #2 Effects			7.64%	15.31%	12.03%	5.37%	3.24%	7.96%	10.60%	7.34%	12.11%	9.88%	
MEAN	9.15%												
SDEV	3.37%												
Half-Lgth	1.18%	t.85 =	1.10814										
Upper	10.33%												
Lower	7.96%												
Signif?	Yes												
Interaction Effects			-0.40%	-4.09%	-5.88%	3.41%	-5.83%	-0.82%	-6.30%	0.27%	2.20%	2.83%	
MEAN	-1.46%												
SDEV	3.59%												
Half-Lgth	1.26%												
Upper	-0.20%												
Lower	-2.72%												
Signif?	Yes												

Advanced Field Artillery System Study

MOE = Detection Ratio for TOT Missions
Block Name: DR_TOT

Design Point	TOT	Tgt Type	Factor Interaction	Run 1	Run 2	Run 3	Run 4	Run 5	Run 6	Run 7	Run 8	Run 9	Run 10	Average
1	-	-	+	32.26	26.17	21.54	28.2	19.36	20.9	26.16	22.98	27.19	29.93	24.67
2	+	-	-	29.56	20.8	25.08	30.89	21.77	26.09	28.39	27.38	27.9	29.77	26.25
3	-	+	-	20.56	22.91	24.98	22.57	21.95	20.68	24.21	18.61	22.65	24.6	22.19
4	+	+	+	20.32	20.89	21.07	24.82	23.53	17.88	21.14	23.38	26.1	28.88	22.28

Factor#1 Effects				-1.47	-3.695	-0.185	2.47	1.995	1.195	-0.42	4.585	2.08	2.06
MEAN	0.8615												
SDEV	2.229437												
Half-Lgth	0.78125												
Upper	1.64275												
Lower	0.08025												
Signif?	Yes												
Factor #2 Effects				-10.47	-1.585	-0.285	-5.85	2.175	-4.215	-4.6	-4.185	-3.17	-3.11
MEAN	-3.5295												
SDEV	3.205546												
Half-Lgth	1.123302	t.85 =	1.10814										
Upper	-2.4062												
Lower	-4.6528												
Signif?	Yes												
Interaction Effects				1.23	1.675	-3.725	-0.22	-0.415	-3.995	-2.65	0.185	1.37	2.22
MEAN	-0.4325												
SDEV	2.153283												
Half-Lgth	0.754563												
Upper	0.322063												
Lower	-1.18706												
Signif?	No												

Advanced Field Artillery System Study

MOE = Rounds/Kill for TOT Missions
Block Name: RPK_TOT

Design Point	TOT	Tgt Type	Factor Interaction	Run 1	Run 2	Run 3	Run 4	Run 5	Run 6	Run 7	Run 8	Run 9	Run 10	Average
1	-	-	+	5.2	5.6	6.6	4.1	6.8	5.3	5	5.4	4.9	5.6	5.4
2	+	-	-	5	6	5.5	6.6	4.9	5.6	3.8	5.2	5.8	6.4	5.6
3	-	+	-	3.7	2.8	3.1	3.6	4.1	3.3	2.9	3.9	3	4.4	3.4
4	+	+	+	4.1	3.7	4.2	3.9	4.6	3.8	3.3	3.4	3.3	3.6	3.8

Factor#1 Effects			0.1	0.65	2.22E-16	1.4	-0.7	0.4	-0.4	-0.35	0.6	2.22E-16
MEAN	0.17												
SDEV	0.582752												
Half-Lgth	0.204211												
Upper	0.374211												
Lower	-0.03421												
Signif?	No												
Factor #2 Effects			-1.2	-2.55	-2.4	-1.6	-1.5	-1.9	-1.3	-1.65	-2.2	-2
MEAN	-1.83												
SDEV	0.434281												
Half-Lgth	0.152183	t.85 =	1.10814										
Upper	-1.67782												
Lower	-1.98218												
Signif?	Yes												
Interaction Effects			0.3	0.25	1.1	-1.1	1.2	0.1	0.8	-0.15	-0.3	-0.8
MEAN	0.14												
SDEV	0.722426												
Half-Lgth	0.253156												
Upper	0.393156												
Lower	-0.11316												
Signif?	No												

Advanced Field Artillery System Study

MOE = Engagement Ranges of Direct Fire Systems for TOT Missions
Block Name: ER_TOT

Design Point	TOT	Tgt Type	Factor Interaction	Run 1	Run 2	Run 3	Run 4	Run 5	Run 6	Run 7	Run 8	Run 9	Run 10	Average
1	-	-	+	3214	3153	3043	3120	3138	3195	3233	3085	3014	3185	3133
2	+	-	-	3194	3151	3181	3145	3116	3137	3142	3257	3124	3080	3151
3	-	+	-	3214	3083	2846	3168	3071	3045	2973	2994	3074	3098	3057
4	+	+	+	3415	3379	3318	3510	3384	3381	3439	3484	3446	3451	3417

Factor#1 Effects				90.5	147	305	183.5	145.5	139	187.5	331	241	124	
MEAN	189.4													
SDEV	75.1255													
Half-Lgth	26.32582													
Upper	215.7258													
Lower	163.0742													
Signif?	Yes													
Factor #2 Effects				110.5	79	-30	206.5	100.5	47	18.5	68	191	142	
MEAN	93.3													
SDEV	69.90358													
Half-Lgth	24.49594		t.85 =	1.10814										
Upper	117.7959													
Lower	68.80406													
Signif?	Yes													
Interaction Effects				110.5	149	167	158.5	167.5	197	278.5	159	131	229	
MEAN	174.7													
SDEV	46.40269													
Half-Lgth	16.26065													
Upper	190.9606													
Lower	158.4394													
Signif?	Yes													

Advanced Field Artillery System Study

MOE = # Indirect Fire Kills of Red for TOT Missions
Block Name: IDFK_TOT

Design Point	TOT	Tgt Type	Factor Interaction	Run 1	Run 2	Run 3	Run 4	Run 5	Run 6	Run 7	Run 8	Run 9	Run 10	Average
1	-	-	+	93	85	73	117	71	90	95	89	97	86	89.6
2	+	-	-	102	85	93	78	105	92	135	99	88	80	95.7
3	-	+	-	129	168	155	135	117	146	163	122	158	105	140.1
4	+	+	+	126	137	121	132	112	134	153	152	156	142	136.5
				3	-15.5	-7	-21	14.5	-5	15	20	-5.5	15.5	
				30	67.5	55	36	26.5	49	43	43	64.5	40.5	
				-6	-15.5	-27	18	-19.5	-7	-25	10	3.5	21.5	

Factor#1 Effects	
MEAN	1.4
SDEV	13.60294
Half-Lgth	4.766806
Upper	6.166806
Lower	-3.36681
Signif?	No

Factor #2 Effects	
MEAN	45.5
SDEV	12.94797
Half-Lgth	4.537289
Upper	50.03729
Lower	40.96271
Signif?	Yes

t.85 = 1.10814

Interaction Effects	
MEAN	-4.7
SDEV	16.54418
Half-Lgth	5.797489
Upper	1.097489
Lower	-10.4975
Signif?	No

Appendix C
Factorial Design Analysis: ROF

Advanced Field Artillery System Study

MOE = Percent Contribution of AFAS for ROF Missions
Block Name: PER_ROF

Design Point	ROF	Tgt Type	Factor Interaction	Run 1	Run 2	Run 3	Run 4	Run 5	Run 6	Run 7	Run 8	Run 9	Run 10	Average
1	-	-	+	32.00%	26.49%	20.19%	16.62%	21.94%	32.69%	38.16%	23.04%	22.13%	20.06%	25.46%
2	+	-	-	26.49%	34.33%	28.00%	27.44%	25.13%	31.13%	34.25%	19.77%	27.37%	33.24%	28.70%
3	-	+	-	33.07%	36.50%	30.95%	39.72%	24.87%	34.77%	33.58%	25.81%	36.28%	37.36%	33.30%
4	+	+	+	34.64%	37.53%	33.33%	37.32%	34.55%	24.14%	38.35%	33.58%	34.08%	33.66%	34.22%

Factor#1 Effects				-1.97%	4.44%	5.10%	4.21%	6.44%	-6.10%	0.43%	2.25%	1.52%	4.74%	
MEAN	2.11%													
SDEV	3.63%													
Half-Lgth	1.27%													
Upper	3.38%													
Lower	0.83%													
Signif?	Yes													
Factor #2 Effects				4.61%	6.61%	8.04%	16.49%	6.17%	-2.46%	-0.24%	8.29%	10.43%	8.86%	
MEAN	6.68%													
SDEV	5.05%													
Half-Lgth	1.77%	t.85 =	110.81%											
Upper	8.45%													
Lower	4.91%													
Signif?	Yes													
Interaction Effects				3.54%	-3.40%	-2.72%	-6.61%	3.24%	-4.54%	4.34%	5.52%	-3.72%	-8.44%	
MEAN	-1.28%													
SDEV	4.74%													
Half-Lgth	1.66%													
Upper	0.38%													
Lower	-2.94%													
Signif?	No													

MOE = Detection Ratio for ROF Missions
Block Name: DR_ROF

Design Point	ROF	Tgt Type	Factor Interaction	Run 1	Run 2	Run 3	Run 4	Run 5	Run 6	Run 7	Run 8	Run 9	Run 10	Average
1	-	-	+	28.12	19	22.12	22.21	21.14	23.82	28.23	24.04	20.81	17.74	22.14
2	+	-	-	24.49	25.53	21.56	26.21	23.84	20.26	23.68	20.85	24.45	27.69	23.58
3	-	+	-	24.24	25.32	21.84	21.71	23.56	21.14	24.13	19.09	22.28	23.02	22.44
4	+	+	+	19.48	23.78	19.05	19.91	24.54	18.48	22.12	21.67	18.32	20.98	20.67

Factor#1 Effects				-4.195	2.495	-1.675	1.1	1.84	-3.11	-3.28	-0.305	-0.16	3.955	
MEAN	-0.3335													
SDEV	2.574941													
Half-Lgth	0.902323													
Upper	0.568823													
Lower	-1.23582													
Signif?	No													
Factor #2 Effects				-4.445	2.285	-1.395	-3.4	1.56	-2.23	-2.83	-2.065	-2.33	-0.715	
MEAN	-1.5565													
SDEV	1.99695													
Half-Lgth	0.699781	t.85 =	1.10814											
Upper	-0.85672													
Lower	-2.25628													
Signif?	Yes													
Interaction Effects				-0.565	-4.035	-1.115	-2.9	-0.86	0.45	1.27	2.885	-3.8	-5.995	
MEAN	-1.4665													
SDEV	2.569157													
Half-Lgth	0.900296													
Upper	-0.5662													
Lower	-2.3668													
Signif?	Yes													

Advanced Field Artillery System Study

MOE = Engagement Ranges of Direct Fire Systems for ROF Missions
Block Name: ER_ROF

Design Point	ROF	Tgt Type	Factor Interaction	Run 1	Run 2	Run 3	Run 4	Run 5	Run 6	Run 7	Run 8	Run 9	Run 10	Average
1	-	-	+	3085	3171	3132	3022	3074	3023	3294	3166	3023	3006	3090
2	+	-	-	3135	3086	3060	3083	3096	3088	3177	2972	3100	3045	3083
3	-	+	-	3498	3496	3267	3425	3465	3416	3515	3294	3476	3470	3429
4	+	+	+	3147	3113	3035	3186	3125	3023	3232	3110	3140	3053	3114

Factor#1 Effects				-150.5	-234	-152	-89	-159	-164	-200	-189	-129.5	-189	
MEAN	-165.6													
SDEV	38.1928													
Half-Lgth	13.3837													
Upper	-152.216													
Lower	-178.984													
Signif?	Yes													
Factor #2 Effects				212.5	176	55	253	210	164	138	133	246.5	236	
MEAN	182.4													
SDEV	58.86926													
Half-Lgth	20.62924		t.85 =	1.10814										
Upper	203.0292													
Lower	161.7708													
Signif?	Yes													
Interaction Effects				-200.5	-149	-80	-150	-181	-229	-83	5	-206.5	-228	
MEAN	-150.2													
SDEV	72.41761													
Half-Lgth	25.37691													
Upper	-124.823													
Lower	-175.577													
Signif?	Yes													

Advanced Field Artillery System Study

MOE = #Indirect Fire Kills of RED for ROF Missions
Block Name: IDFK_ROF

Design Point	ROF	Tgt Type	Factor Interaction	Run 1	Run 2	Run 3	Run 4	Run 5	Run 6	Run 7	Run 8	Run 9	Run 10	Average
1	-	-	+	120	98	74	59	77	119	145	85	77	70	92.4
2	+	-	-	98	126	105	104	95	113	125	70	98	116	105
3	-	+	-	126	142	104	143	99	129	135	96	156	139	126.9
4	+	+	+	132	158	138	159	142	91	158	135	153	139	140.5

Factor#1 Effects				-8	22	32.5	30.5	30.5	-22	1.5	12	9	23
MEAN	13.1												
SDEV	17.28844												
Half-Lgth	6.058294												
Upper	19.15829												
Lower	7.041706												
Signif?	Yes												
Factor #2 Effects				20	38	31.5	69.5	34.5	-6	11.5	38	67	46
MEAN	35												
SDEV	21.96361												
Half-Lgth	7.696589		t.85 =	1.10814									
Upper	42.69659												
Lower	27.30341												
Signif?	Yes												
Interaction Effects				14	-6	1.5	-14.5	12.5	-16	21.5	27	-12	-23
MEAN	0.5												
SDEV	16.48787												
Half-Lgth	5.777757												
Upper	6.277757												
Lower	-5.27776												
Signif?	No												

Advanced Field Artillery System Study

MOE = # Direct Fire Kills of RED for ROF Missions
Block Name: DFK_ROF

Design Point	ROF	Tgt Type	Factor Interaction	Run 1	Run 2	Run 3	Run 4	Run 5	Run 6	Run 7	Run 8	Run 9	Run 10	Average
1	-	-	+	255	272	294	296	274	245	234	284	271	279	270.5
2	+	-	-	272	241	270	275	283	250	240	284	260	233	260.8
3	-	+	-	255	247	232	217	299	242	267	276	274	233	254.2
4	+	+	+	249	263	276	267	269	286	254	267	296	274	270.1

Factor#1 Effects				5.5	-7.5	10	14.5	-10.5	24.5	-3.5	-4.5	5.5	-2.5
MEAN	3.15												
SDEV	10.37798												
Half-Lgth	3.6367												
Upper	6.7867												
Lower	-0.4867												
Signif?	No												
Factor #2 Effects				-11.5	-1.5	-28	-43.5	5.5	16.5	23.5	-12.5	19.5	-2.5
MEAN	-3.45												
SDEV	20.22183												
Half-Lgth	7.086228	t.85 =	1.10814										
Upper	3.636228												
Lower	-10.5362												
Signif?	No												
Interaction Effects				-11.5	23.5	34	35.5	-19.5	19.5	-9.5	-4.5	16.5	43.5
MEAN	12.75												
SDEV	21.23823												
Half-Lgth	7.4424												
Upper	20.1924												
Lower	5.3076												
Signif?	Yes												

Advanced Field Artillery System Study

MOE = Rounds/Kill for ROF Missions
Block Name: RPK_ROF

Design Point	ROF	Tgt Type	Factor Interaction	Run 1	Run 2	Run 3	Run 4	Run 5	Run 6	Run 7	Run 8	Run 9	Run 10	Average
1	-	-	+	4	4.9	6.5	8.1	6.2	4	3.3	5.6	6.2	6.8	5.2
2	+	-	-	4.9	3.8	4.6	4.6	5	4.2	3.8	6.8	4.9	4.1	4.6
3	-	+	-	3.8	3.4	4.6	3.4	4.8	3.7	3.6	5	3.1	3.4	3.8
4	+	+	+	3.6	3	3.5	3	3.4	5.3	3	3.6	3.1	3.4	3.4

Factor#1 Effects			0.35	-0.75	-1.5	-1.95	-1.3	0.9	-0.05	-0.1	-0.65	-1.35
MEAN	-0.64											
SDEV	0.860174											
Half-Lgth	0.301426											
Upper	-0.33857											
Lower	-0.94143											
Signif?	Yes											
Factor #2 Effects			-0.75	-1.15	-1.5	-3.15	-1.5	0.4	-0.25	-1.9	-2.45	-2.05
MEAN	-1.43											
SDEV	0.994786											
Half-Lgth	0.348598	t.85 =	1.10814									
Upper	-1.0814											
Lower	-1.7786											
Signif?	Yes											
Interaction Effects			-0.55	0.35	0.4	1.55	-0.1	0.7	-0.55	-1.3	0.65	1.35
MEAN	0.25											
SDEV	0.842615											
Half-Lgth	0.295273											
Upper	0.545273											
Lower	-0.04527											
Signif?	No											

Appendix D
Response Surface Methodology Calculations: TOT

Advanced Field Artillery System Study

Response Surface Methodology Calculations

Factor	Coeff	(-)	(+)	Variable	Indep
		4	8	5	-0.5
TOT	0.085	4	8	6	0
TypeTgt	-0.915	20%	60%	20%	-1
Interact	0.07			60%	1
Avg Response	4.55				

E[R(TOT,TGT)] = Avg Response + TOT Coeff*TOT_Variable + TGT Coeff*TGT_Vari
E[R(TOT=5,TGT=20%S)] = 5.4575
E[R(TOT=6,TGT=20%S)] = 5.465
E[R(TOT=6,TGT=60%S)] = 3.635

TOT_variable = 2*(Variable - Mean)/ (8 rds/TOT - 4 rds/TOT)
= 2*(Variable - 6)/ (4)

Tgt_variable = 2*(Variable - Mean)/ (60%SoftTgts - 20%SoftTgts)
= 2*(Variable - 0.4)/ (0.4)

MOE = Rounds/Kill for TOT Missions
Block Name: RPK_TOTRSM

RDS/TOT= 6	Run 1	Run 2	Run 3	Run 4	Run 5	Run 6	Run 7	Run 8	Run 9	Run 10	Average	Prediction	Diff
20%Soft/80%Hard	5.8	5.6	5.2	6.2	6.6	5.2	3.7	5.7	6.3	7	5.6	5.465	0.135
60%Soft/40%Hard	4.1	3.6	3.2	3.8	4.3	4	3.2	4.1	3.8	3.3	3.7	3.635	0.065

Comparison of RSM vs. Actual Simulation Results

RDS/TOT= 6	Mean	StndDev	Half-lgth	Upper	Lower	Predict	In CI?	%Diff from the Mean
20%Soft/80%Hard	5.730	0.873	0.306	6.036	5.424	5.465	Yes	4.62%
60%Soft/40%Hard	3.740	0.380	0.133	3.873	3.607	3.635	Yes	2.81%

Response Surface Methodology Calculations

Factor	Coeff	(-)	(+)	Variable	Indep
		4	8	5	-0.5
TOT	-7.525	4	8	6	0
TypeTgt	-3.275	20%	60%	20%	-1
Interact	4.225			60%	1
Avg Response	250.775				

E[R(TOT,TGT)] = Avg Response + TOT Coeff*TOT_Variable + TGT Coeff*TGT_Vari

E[R(TOT=5,TGT=20%S)] = 259.925

E[R(TOT=6,TGT=20%S)] = 254.05

E[R(TOT=6,TGT=60%S)] = 247.5

2	277
3	272
4	266
5	260
6	254
7	248
8	242

TOT_variable = 2*(Variable - Mean)/ (8 rds/TOT - 4 rds/TOT)
= 2*(Variable - 6)/ (4)

Tgt_variable = 2*(Variable - Mean)/ (60%SoftTgts - 20%SoftTgts)
= 2*(Variable - 0.4)/ (0.4)

MOE = # Direct Fire Kills of RED for TOT M
Block Name: DFK_TOTRSM

RDS/TOT= 6	Run 1	Run 2	Run 3	Run 4	Run 5	Run 6	Run 7	Run 8	Run 9	Run 10	Average	Prediction	Diff
20%Soft/80%Hard	258	258	228	276	265	226	218	301	259	265	255.4	254.05	1.35
60%Soft/40%Hard	287	239	225	260	287	221	248	265	256	262	255	247.5	7.5

Comparison of RSM vs. Actual Simulation Results

RDS/TOT= 6	Mean	StndDev	Half-lgth	Upper	Lower	Predict	In CI?	%Diff from the Mean
20%Soft/80%Hard	255.400	23.934	8.387	263.787	247.013	254.050	Yes	0.53%
60%Soft/40%Hard	255.000	21.410	7.503	262.503	247.497	247.500	Yes	2.94%

Response Surface Methodology Calculations

Factor	Coeff	(-)	(+)	Variable	Indep
		4	8	5	-0.5
TOT	0.7	4	8	6	0
TypeTgt	22.75	20%	60%	20%	-1
Interact	-2.35			60%	1
Avg Response	115.475				

E[R(TOT,TGT)] = Avg Response + TOT Coeff*TOT_Variable + TGT Coeff*TGT_Vari
E[R(TOT=5,TGT=20%S)] = 91.2
E[R(TOT=6,TGT=20%S)] = 92.725
E[R(TOT=6,TGT=60%S)] = 138.225

TOT_variable = 2*(Variable - Mean)/ (8 rds/TOT - 4 rds/TOT)
= 2*(Variable - 6)/ (4)

Tgt_variable = 2*(Variable - Mean)/ (60%SoftTgts - 20%SoftTgts)
= 2*(Variable - 0.4)/ (0.4)

MOE = # Indirect Fire Kills of Red for TOT
Block Name: IDFK_TOTRSM

RDS/TOT= 6	Run 1	Run 2	Run 3	Run 4	Run 5	Run 6	Run 7	Run 8	Run 9	Run 10	Average	Prediction	Diff
20%Soft/80%Hard	83	85	92	78	73	92	131	84	76	69	86.3	92.725	6.425
60%Soft/40%Hard	118	133	150	127	111	120	152	116	127	146	130	138.225	8.225

Comparison of RSM vs. Actual Simulation Results

RDS/TOT= 6	Mean	StndDev	Half-lgth	Upper	Lower	Predict	In CI?	%Diff from the Mean
20%Soft/80%Hard	86.300	16.529	5.792	92.092	80.508	92.725	No	7.44%
60%Soft/40%Hard	130.000	14.029	4.916	134.916	125.084	138.225	No	6.33%

Advanced Field Artillery System Study

Response Surface Methodology Calculations

Factor	Coeff	(-)	(+)	Variable	Indep
		4	8	5	-0.5
TOT	94.7	4	8	6	0
TypeTgt	46.65	20%	60%	20%	-1
Interact	87.35			60%	1
Avg Response	3189.5				

E[R(TOT,TGT)] = Avg Response + TOT Coeff*TOT_Variable + TGT Coeff*TGT_Vari
E[R(TOT=5,TGT=20%S)] = 3139.175
E[R(TOT=6,TGT=20%S)] = 3142.85
E[R(TOT=6,TGT=60%S)] = 3236.15

TOT_variable = 2*(Variable - Mean)/ (8 rds/TOT - 4 rds/TOT)
= 2*(Variable - 6)/ (4)

Tgt_variable = 2*(Variable - Mean)/ (60%SoftTgts - 20%SoftTgts)
= 2*(Variable - 0.4)/ (0.4)

MOE = Direct Fire Engagement Ranges for TOT Mission
Block Name: ER_TOTRSM

RDS/TOT= 6	Run 1	Run 2	Run 3	Run 4	Run 5	Run 6	Run 7	Run 8	Run 9	Run 10	Average	Prediction	Diff
20%Soft/80%Hard	3399	3453	3427	3483	3450	3438	3501	3292	3433	3459	3427	3142.85	284.15
60%Soft/40%Hard	3480	3407	3328	3454	3329	3352	3482	3371	3423	3388	3400	3236.15	163.85

Comparison of RSM vs. Actual Simulation Results

RDS/TOT= 6	Mean	StndDev	Half-lgth	Upper	Lower	Predict	In CI?	%Diff from the Mean
20%Soft/80%Hard	3433.500	54.392	19.060	3452.560	3414.440	3142.850	No	8.47%
60%Soft/40%Hard	3401.400	54.875	19.229	3420.629	3382.171	3236.150	No	4.86%

Response Surface Methodology Calculations

Factor	Coeff	(-)	(+)	Variable	Indep
		4	8	5	-0.5
TOT	0.43075	4	8	6	0
TypeTgt	-1.76475	20%	60%	20%	-1
Interact	-0.21625			60%	1
Avg Response	23.8475				

E[R(TOT,TGT)] = Avg Response + TOT Coeff*TOT_Variable + TGT Coeff*TGT_Vari
E[R(TOT=5,TGT=20%S)] = 25.28875
E[R(TOT=6,TGT=20%S)] = 25.61225
E[R(TOT=6,TGT=60%S)] = 22.08275

TOT_variable = 2*(Variable - Mean)/ (8 rds/TOT - 4 rds/TOT)
= 2*(Variable - 6)/ (4)

Tgt_variable = 2*(Variable - Mean)/ (60%SoftTgts - 20%SoftTgts)
= 2*(Variable - 0.4)/ (0.4)

MOE = Detection Ratio for TOT Missions
Block Name: DR_TOTRSM

RDS/TOT= 6	Run 1	Run 2	Run 3	Run 4	Run 5	Run 6	Run 7	Run 8	Run 9	Run 10	Average	Prediction	Diff
20%Soft/80%Hard	23.41	29.17	24.2	26.41	22.06	24.87	26.44	20.39	24.4	24.04	24.11	25.61225	1.50225
60%Soft/40%Hard	19.91	22.75	22.26	23.41	19.45	24.42	26.42	18.44	20.43	29.33	22.22	22.08275	0.13725

Comparison of RSM vs. Actual Simulation Results

RDS/TOT= 6	Mean	StndDev	Half-lgth	Upper	Lower	Predict	In CI?	%Diff from the Mean
20%Soft/80%Hard	24.539	2.317	0.812	25.351	23.727	25.612	No	4.37%
60%Soft/40%Hard	22.682	3.211	1.125	23.807	21.557	22.083	Yes	2.64%

Response Surface Methodology Calculations

Factor	Coeff	(-)	(+)	Variable	Indep
		4	8	5	-0.5
TOT	0.81%	4	8	6	0
TypeTgt	4.57%	20%	60%	20%	-1
Interact	-0.73%			60%	1
Avg Response	31.31%				

E[R(TOT,TGT)] = Avg Response + TOT Coeff*TOT_Variable + TGT Coeff*TGT_Vari
E[R(TOT=5,TGT=20%S)] = 25.96%
E[R(TOT=6,TGT=20%S)] = 26.73%
E[R(TOT=6,TGT=60%S)] = 35.88%

TOT_variable = 2*(Variable - Mean)/ (8 rds/TOT - 4 rds/TOT)
= 2*(Variable - 6)/ (4)

Tgt_variable = 2*(Variable - Mean)/ (60%SoftTgts - 20%SoftTgts)
= 2*(Variable - 0.4)/ (0.4)

MOE = Percent Contribution of AFAS for TOT Missions
Block Name: PER_TOTRSM

RDS/TOT= 6	Run 1	Run 2	Run 3	Run 4	Run 5	Run 6	Run 7	Run 8	Run 9	Run 10	Average	Prediction	Diff
20%Soft/80%Hard	24.34%	24.78%	28.75%	22.03%	21.60%	28.93%	37.54%	21.82%	22.69%	20.66%	25.26%	26.73%	1.47%
60%Soft/40%Hard	29.14%	35.75%	40.00%	32.82%	27.89%	35.19%	38.00%	30.45%	33.16%	35.78%	33.77%	35.88%	2.11%

Comparison of RSM vs. Actual Simulation Results

RDS/TOT= 6	Mean	StndDev	Half-lgth	Upper	Lower	Predict	In CI?	%Diff from the Mean
20%Soft/80%Hard	0.253	0.049	0.017	0.270	0.236	0.267	Yes	5.60%
60%Soft/40%Hard	0.338	0.037	0.013	0.351	0.325	0.359	No	6.09%

Appendix E
Response Surface Methodology Calculations: ROF

Response Surface Methodology Calculations

Factor	Coeff	(-)	(+)	Variable	Indep
		8	12	9	-0.5
TOT	0.010525	8	12	10	0
TypeTgt	0.033405	20%	60%	20%	-1
Interact	-0.00639			60%	1
Avg Response	0.3042				

E[R(ROF,TGT)] = Avg Response + ROF Coeff*ROF_Variable + TGT Coeff*TGT_Vari
E[R(ROF=9,TGT=20%S)] = 26.23%
E[R(ROF=10,TGT=20%S)] = 27.08%
E[R(ROF=10,TGT=60%S)] = 33.76%

ROF_variable = 2*(Variable - Mean)/ (12 rds/min - 8 rds/min)
= 2*(Variable - 10)/ (4)

Tgt_variable = 2*(Variable - Mean)/ (60%SoftTgts - 20%SoftTgts)
= 2*(Variable - 0.4)/ (0.4)

MOE = Percent Contribution of AFAS for RO
Block Name: PER_ROFRSM

RDS/MIN= 10	Run 1	Run 2	Run 3	Run 4	Run 5	Run 6	Run 7	Run 8	Run 9	Run 10	Average	Prediction	Diff
20%Soft/80%Hard	21.45%	30.08%	21.83%	24.80%	23.84%	31.39%	35.44%	26.04%	21.79%	28.00%	26.45%	27.08%	0.63%
60%Soft/40%Hard	39.75%	38.44%	35.48%	37.16%	34.14%	40.47%	47.74%	38.32%	35.77%	36.82%	38.39%	33.76%	4.63%
													39.40%
													37.38%

Comparison of RSM vs. Actual Simulation Results

RDS/MIN= 10	Mean	StndDev	Half-lgth	Upper	Lower	Predict	In CI?	%Diff from the Mean
20%Soft/80%Hard	0.265	0.045	0.016	0.280	0.249	0.271	Yes	2.32%
60%Soft/40%Hard	0.384	0.036	0.013	0.397	0.371	0.338	No	12.10%

Advanced Field Artillery System Study

Response Surface Methodology Calculations

Factor	Coeff	(-)	(+)	Variable	Indep
		8	12	9	-0.5
ROF	-0.16675	8	12	10	0
TypeTgt	-0.77825	20%	60%	20%	-1
Interact	-0.73325			60%	1
Avg Response	22.2075				

E[R(ROF,TGT)] = Avg Response + ROF Coeff*ROF_Variable + TGT Coeff*TGT_Vari
E[R(ROF=9,TGT=20%S)] = 22.7025
E[R(ROF=10,TGT=20%S)] = 22.98575
E[R(ROF=10,TGT=60%S)] = 21.42925

ROF_variable = 2*(Variable - Mean)/ (12 rds/min - 8 rds/min)
= 2*(Variable - 10)/ (4)

Tgt_variable = 2*(Variable - Mean)/ (60%SoftTgts - 20%SoftTgts)
= 2*(Variable - 0.4)/ (0.4)

MOE = Detection Ratio for ROF Missions
Block Name: DR_ROFRSM

RDS/MIN= 10	Run 1	Run 2	Run 3	Run 4	Run 5	Run 6	Run 7	Run 8	Run 9	Run 10	Average	Prediction	Diff
20%Soft/80%Hard	20.9	19.17	23.09	24.59	19.38	21.22	32.47	21.25	20.15	23.7	22.09	22.98575	0.89575
60%Soft/40%Hard	23.28	25.64	21.65	21.78	26.75	22.75	20.83	19.35	24.44	23.72	22.8	21.42925	1.37075

Comparison of RSM vs. Actual Simulation Results

RDS/MIN= 10	Mean	StndDev	Half-lgth	Upper	Lower	Predict	In CI?	%Diff from the Mean
20%Soft/80%Hard	22.592	3.709	1.300	23.892	21.292	22.986	Yes	1.74%
60%Soft/40%Hard	23.019	2.124	0.744	23.763	22.275	21.429	No	6.91%

Advanced Field Artillery System Study

Response Surface Methodology Calculations

Factor	Coeff	(-)	(+)	Variable	Indep
		8	12	9	-0.5
ROF	1.575	8	12	10	0
TypeTgt	-1.725	20%	60%	20%	-1
Interact	6.375			60%	1
Avg Response	263.9				

E[R(ROF,TGT)] = Avg Response + ROF Coeff*ROF_Variable + TGT Coeff*TGT_Vari
E[R(ROF=9,TGT=20%S)] = 268.025
E[R(ROF=10,TGT=20%S)] = 265.625
E[R(ROF=10,TGT=60%S)] = 262.175

ROF_variable = 2*(Variable - Mean)/ (12 rds/min - 8 rds/min)
= 2*(Variable - 10)/ (4)

Tgt_variable = 2*(Variable - Mean)/ (60%SoftTgts - 20%SoftTgts)
= 2*(Variable - 0.4)/ (0.4)

MOE = # Direct Fire Kills of RED for ROF M
Block Name: DFK_ROFRSM

RDS/MIN= 10	Run 1	Run 2	Run 3	Run 4	Run 5	Run 6	Run 7	Run 8	Run 9	Run 10	Average	Prediction	Diff
20%Soft/80%Hard	293	265	290	276	278	247	235	267	280	252	268.3	265.625	2.675
60%Soft/40%Hard	238	261	240	230	272	253	197	243	246	266	244.6	262.175	17.575

Comparison of RSM vs. Actual Simulation Results

RDS/MIN= 10	Mean	StndDev	Half-lgth	Upper	Lower	Predict	In CI?	%Diff from the Mean
20%Soft/80%Hard	268.300	17.922	6.280	274.580	262.020	265.625	Yes	1.00%
60%Soft/40%Hard	244.600	20.240	7.092	251.692	237.508	262.175	No	7.19%

Advanced Field Artillery System Study

Response Surface Methodology Calculations

Factor	Coeff	(-)	(+)	Variable	Indep
		8	12	9	-0.5
ROF	-0.32	8	12	10	0
TypeTgt	-0.715	20%	60%	20%	-1
Interact	0.125			60%	1
Avg Response	4.25				

E[R(ROF,TGT)] = Avg Response + ROF Coeff*ROF_Variable + TGT Coeff*TGT_Vari
E[R(ROF=9,TGT=20%S)] = 5.1875
E[R(ROF=10,TGT=20%S)] = 4.965
E[R(ROF=10,TGT=60%S)] = 3.535

ROF_variable = 2*(Variable - Mean)/ (12 rds/min - 8 rds/min)
= 2*(Variable - 10)/ (4)

Tgt_variable = 2*(Variable - Mean)/ (60%SoftTgts - 20%SoftTgts)
= 2*(Variable - 0.4)/ (0.4)

MOE = Rounds/Kill for ROF Missions
Block Name: RPK_ROFRSM

RDS/MIN= 10	Run 1	Run 2	Run 3	Run 4	Run 5	Run 6	Run 7	Run 8	Run 9	Run 10	Average	Prediction	Diff
20%Soft/80%Hard	6	4.2	5.9	5.3	5.5	4.2	3.7	5.1	6.2	4.9	5	4.965	0.035
60%Soft/40%Hard	3	2.9	3.6	3.5	3.4	3.1	2.8	2.7	3.2	3.5	3.1	3.535	0.435

Comparison of RSM vs. Actual Simulation Results

RDS/MIN= 10	Mean	StndDev	Half-lgth	Upper	Lower	Predict	In CI?	%Diff from the Mean
20%Soft/80%Hard	5.100	0.805	0.282	5.382	4.818	4.965	Yes	2.65%
60%Soft/40%Hard	3.170	0.303	0.106	3.276	3.064	3.535	No	11.51%

Response Surface Methodology Calculations

Factor	Coeff	(-)	(+)	Variable	Indep
		8	12	9	-0.5
ROF	-82.8	8	12	10	0
TypeTgt	91.2	20%	60%	20%	-1
Interact	-75.1			60%	1
Avg Response	3179				

E[R(ROF,TGT)] = Avg Response + ROF Coeff*ROF_Variable + TGT Coeff*TGT_Vari
E[R(ROF=9,TGT=20%S)] = 3091.65
E[R(ROF=10,TGT=20%S)] = 3087.8
E[R(ROF=10,TGT=60%S)] = 3270.2

ROF_variable = 2*(Variable - Mean)/ (12 rds/min - 8 rds/min)
= 2*(Variable - 10)/ (4)

Tgt_variable = 2*(Variable - Mean)/ (60%SoftTgts - 20%SoftTgts)
= 2*(Variable - 0.4)/ (0.4)

MOE = Blue Direct Fire Engagement Ranges
Block Name: ER_ROFRSM

RDS/MIN= 10	Run 1	Run 2	Run 3	Run 4	Run 5	Run 6	Run 7	Run 8	Run 9	Run 10	Average	Prediction	Diff
20%Soft/80%Hard	3438	3442	3388	3453	3477	3494	3486	3428	3308	3483	3438	3087.8	350.2
60%Soft/40%Hard	3468	3532	3340	3331	3383	3484	3364	3374	3502	3492	3425	3270.2	154.8

Comparison of RSM vs. Actual Simulation Results

RDS/MIN= 10	Mean	StndDev	Half-lgth	Upper	Lower	Predict	In CI?	%Diff from the Mean
20%Soft/80%Hard	3439.700	53.571	18.772	3458.472	3420.928	3087.800	No	10.23%
60%Soft/40%Hard	3427.000	71.627	25.100	3452.100	3401.900	3270.200	No	4.58%

Advanced Field Artillery System Study

Response Surface Methodology Calculations

Factor	Coeff	(-)	(+)	Variable	Indep
		8	12	9	-0.5
ROF	6.55	8	12	10	0
TypeTgt	17.5	20%	60%	20%	-1
Interact	0.25			60%	1
Avg Response	116.2				

E[R(ROF,TGT)] = Avg Response + ROF Coeff*ROF_Variable + TGT Coeff*TGT_Vari
E[R(ROF=9,TGT=20%S)] = 95.55
E[R(ROF=10,TGT=20%S)] = 98.7
E[R(ROF=10,TGT=60%S)] = 133.7

ROF_variable = 2*(Variable - Mean)/ (12 rds/min - 8 rds/min)
= 2*(Variable - 10)/ (4)

Tgt_variable = 2*(Variable - Mean)/ (60%SoftTgts - 20%SoftTgts)
= 2*(Variable - 0.4)/ (0.4)

MOE = # Indirect Fire Kills of RED for ROF
Block Name: IDFK_ROFRSM

RDS/MIN= 10	Run 1	Run 2	Run 3	Run 4	Run 5	Run 6	Run 7	Run 8	Run 9	Run 10	Average	Prediction	Diff
20%Soft/80%Hard	80	114	81	91	87	113	129	94	78	98	96.5	98.7	2.2
60%Soft/40%Hard	157	163	132	136	141	172	180	151	137	155	152.4	133.7	18.7

Comparison of RSM vs. Actual Simulation Results

RDS/MIN= 10	Mean	StndDev	Half-lgth	Upper	Lower	Predict	In CI?	%Diff from the Mean
20%Soft/80%Hard	96.500	16.182	5.670	102.170	90.830	98.700	Yes	2.28%
60%Soft/40%Hard	152.400	15.298	5.361	157.761	147.039	133.700	No	12.27%

Appendix F
1000-Target Methodology by SFC West

1000 Target Methodology

ORCEN• Center of Excellence

1. Based on Soviet-style tank company in wedge formation.

2. 100 target groupings; 10 vehicles per group.

3. Two platoons with 3 vehicles; 1 with 4 (includes HQ tank).

4. One event per method of engagement:

   -- One 8-round volley per group under 8 TOT
   -- Twelve rounds, 5 seconds apart, per group under 12 ROF

5. ROF rounds are spread over a 1-minute attack.

6. Five runs for each method of engagement.

7. Trucks substituted for tanks at the same locations.

1000 Target Analysis

AFAS vs. T-72

	Run 1	Run 2	Run 3	Run 4	Run 5	Mean	Kills/Rnd
4 TOT	43	51	42	43	37	43.2	1.08
6 TOT	62	61	69	58	64	62.8	1.05
8 TOT	69	65	74	69	87	72.8	0.91
8 RPM	92	85	89	70	91	85.4	1.07
10 RPM	118	87	101	92	105	100.6	1.01
12 RPM	139	122	133	115	114	124.6	1.04

AFAS vs. Truck

	Run 1	Run 2	Run 3	Run 4	Run 5	Mean	Kills/Rnd
4 TOT	82	73	81	82	84	80.4	2.01
6 TOT	108	100	106	104	96	102.8	1.71
8 TOT	125	102	114	117	190	129.6	1.62
8 RPM	204	151	172	173	168	173.6	2.17
10 RPM	221	211	232	187	211	212.4	2.12
12 RPM	212	231	223	199	231	219.2	1.83

Appendix G
After-Action Memo by MAJ Watson on AFAS Briefing

OPERATIONS RESEARCH CENTER
UNITED STATES MILITARY ACADEMY
WEST POINT, NEW YORK 10996

MADN-OR

22 July 1992

MEMORANDUM FOR LTC James E. Armstrong, Director ORCEN, USMA

SUBJECT: TDY Trip to Fort Sill, Oklahoma concerning the Advanced Field Artillery System (AFAS).

1. On 19-21 July 92, CPT Jim Watson went to Fort Sill, Oklahoma to attend a briefing by Majors George Stone and Jay Moughon, and SFC West of DMI. Their briefing, which occurred on 20 1300 July 92, covered their work on the Janus(A) combat modeling system regarding the AFAS. They briefed numerous (about 20) civilian and military personnel of the Directorate of Combat Developments (DCD), U.S. Army Field Artillery School. Please see the attached listing of the key personnel who attended.

2. The briefing went quite well with, at times, very lively interaction with the audience concerning the assumptions and set-up of the Janus scenarios which MAJ Stone and MAJ Moughon developed. They seemed very interested in comparing the effects of the AFAS between the Time-on-Target and Rate-of Fire target engagement methods. The briefing concluded with high interest on the part of all key personnel in the DCD to continue with the analysis with some refinements on the scenario set-up, as well as the modeling of key AFAS attributes.

3. I would highly recommend continued work on this project. The resulting analysis would be well received by not only DCD personnel, but also high level Field Artillery and Procurement Action Officers. The refinement of the scenarios could be done nicely by cadets in the Janus Combat Modeling Lab as a SE489 project. In addition, SFC West informed me that COL Karr, the Director of Military Instruction, was very interested in pursuing this project.

4. I would be happy to continue this analysis. As a Field Artilleryman and an ORCEN Analyst, this project would exercise my education and training most appropriately.

James L. Watson, Jr.
CPT, FA
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AFAS KEY PERSONNEL